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LONG-TERM EFFECTS OF AIR POLLUTION
A FIVE-YEAR SURVEILLANCE PROGRAM

May 1971
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Principal Investigator

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16. Abstracts

A program of research on long term problems of air pollution is outlined. The major problem areas are first identified, with no attempt at a formal definition of 'long-term'. Priorities are allocated to the problem areas. Research projects are then identified and tabulated, where they are classified in two ways: according to the space-scale of the phenomena involved and according to the nature of the technique of the recommended attack. The space scales are divided into, local, regional, continental and global. Priorities allocated to the projects by application of the criteria are tabulated. An overall rate of expenditure is proposed and a time-table for work on some major projects is suggested.

(APCO abstract)

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LONG-TERM EFFECTS OF AIR POLLUTION
A FIVE-YEAR RESEARCH PROGRAM

G. D. Robinson
Principal Investigator

May 1971
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THE CENTER FOR THE ENVIRONMENT AND MAN, INC.
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FOREWORD

This outline of a program of research concerned with *The Long-Term Effects of Air Pollution* was prepared at The Center for the Environment and Man, Inc. under Contract CPA-22-69-155 with the Air Pollution Control Office of the Environmental Protection Agency. Dr. John H. Ludwig acted as Project Officer and Mr. R. A. McCormick as Project Scientist.

In the course of the contract a report *"Long-Term Effects of Air Pollution - A Survey," CEM* 4029-400, *June* 1970, was prepared. It has received a wide circulation. The contract also supported the participation of the principal investigator in the MIT Summer Study on Critical Environmental Problems held at Williamstown, Massachusetts in July 1970, where he acted as Chairman of the group concerned with monitoring, and was able to discuss the subject of this report with numerous interested colleagues. Their help is gratefully acknowledged.

The Long-Term Effects of Air Pollution

A Five-Year Research Program

1. Construction of the program and structure of the report

The program set out here is largely based on a study of long-term problems of air pollution which was sponsored by the Air Pollution Control Office (APCO) of the Environmental Protection Agency (EPA) and is summarized in the CEM report, "Long-Term Effects of Air Pollution - A Survey," (CEM 4029-400, June 1970); and on the deliberations and findings of the MIT Study of Critical Environmental Problems in July 1970, (Man's Impact on the Global Environment - Assessment and Recommendations for Action," M.I.T. Press 1970). The major problem areas are first identified. There is no attempt at a formal definition of 'long-term'; in some of the problem areas there are evident effects of air pollution on the shortest of time scales, as well as the identified potential for slow but major influences. Priorities are allocated to the problem areas; these priorities refer only to the long-term aspects of the problem. Criteria for the allocation of the priorities are discussed in Section 2. The problem areas and priorities are listed in Table I and priorities summarized in Table II, which contains a more quantitative estimate of priority in the form of a suggested allocation of available funds.

Research projects are then identified - more or less self-contained areas of research related to the problems and unified by content or technique. They are displayed in Table III, where they are classified in two ways - according to the space-scale of the phenomena involved and according to the nature of the technique of the recommended attack. The space scales are divided into:-

1) Local - areas of less than about 10^2 km^2.

2) Regional - areas of less than about 10^5 km^2.

3) Continental

4) Global

The types of attack are: -

1) Environmental Studies (Tables III A, III B) - Studies involving commonly made observations, or special surveys, of the state of the environment, with no conscious modification of the sources of contaminants.

2) Field Experiments (Tables III C, III D) - Studies involving purposeful modification of the environment or of emissions into the environment. Trials of potential monitoring techniques.

3) Laboratory Experiments (Table III E) - Investigation of the physical - particularly optical - properties of substances which occur as pollutants and of chemical reactions between pollutants in controlled circumstances. Development of monitoring techniques.

4) Theoretical and Numerical Studies (Table III F) - particularly of the type commonly described as 'modeling'.

5) Monitoring (Table III G) - Establishment, within the five-year period, of observations pertinent to the long-term problems with the intention that they should continue beyond the five-year period.

Priorities allocated to the projects by application of the criteria of Section 2 are set out in Table III. In some instances research is in progress or proposed in relation to the shorter term aspects, and in order to remove the possibility of misunderstanding, problems are annotated where the priority of work on short-term effects might (in the author's opinion) be higher than that suggested by the nature of the potential long-term effects. A note is also made of those areas where understanding of the long-term problem is likely to be improved by implementation of the major regional study which EPA has announced. Table IV summarizes the project priorities.

Section 4 contains an expanded description of some of the more important recommended projects, explaining the rationale behind the recommendation of high priority and sketching possible modes of attack. Finally in Section 5 an overall rate of expenditure is proposed and a time-table for work on some major projects, consistent with the proposed expenditure, is suggested.

2. Assessment of Priorities

Priorities are expressed in terms of two indicators (A, B, C) and (1, 2, 3). The first (A, B, C) indicates the nature of the EPA involvement:-

A. EPA should initiate or, if effort already exists, support

B. EPA should cooperate

C. EPA should encourage

The second (1, 2, 3) indicates the priority order for allocation of funds.

The assessment of the nature of EPA involvement is made mainly with reference to the major problem area with which a project is associated. The criterion is the bearing on the problem of EPA's mission of control and abatement, in relation to the missions of other agencies. Application of the criterion is perhaps best illustrated by examples.

The problem of acid precipitation is related to trace gas and particle emissions, which in principle can be eliminated, and is clearly in category A. If, on the other hand, it were to appear that climatic effects of the heat dissipated in all energy conversion activities constituted a serious threat, major policy decisions on population distribution and the disposal of energy reserves would be called for. Except for certain very localized problems, which might be handled by local abatement action, research in this area has been placed in category C. The problem of increasing CO_2 content of the atmosphere and its possible climatic

effect is more difficult to categorize. Agencies immediately involved are those concerned with fuel policy decisions - e.g., nuclear vs fossil fuel, and with the location of populations, but CO_2 is a material product of combustion which can reasonably be called a pollutant. It is, however, extremely unpromising as a candidate for control and abatement and it seems unreasonable to regard research on its potential climatic effect to be primarily the concern of EPA. It has, therefore, been categorized as B.

The criteria for allocation of priority of funding (indicator 1, 2, or 3) are -

- The magnitude of the threat to existing standards of life and existing populations.
- The magnitude, imminence and time-scale of the future threat to currently acceptable standards of life in the light of population projections.
- The relevance to public policy and the degree of public concern.
- The magnitude of the required funding relative to that available.
- The likelihood of a fairly rapid return for money expended.

Because of the widely varying nature of these criteria the assessments are highly subjective. The assessment process may be illustrated by discussing the rationale of the priorities assigned in the major problem areas (Table I).

Polluted (particularly acid) rainfall is a problem of immediate concern which is international in character and has been recognized as a potential source of international disagreement. Large sums of money may be involved - on the one hand in loss of agricultural productivity, on the other in increased manufacturing costs, though the true magnitude of the economic factors is not yet established. The problem, if it is confirmed to be a result of industrial emissions, is soluble in principle by control and abatement of those emissions. There is every indication that the problem would in large measure be understood within a few years if subjected to intensive investigation on a scale of effort which is now available. All criteria point to an A.1 priority.

The other A.1 priority of Table I arises because of the nature of the environmental threat. It concerns possible effects of pollution of the lower stratosphere by supersonic transport aircraft operating in commercially viable numbers. The problems posed are scientifically difficult and there is no reason to be confident that they can be quickly resolved. The priority arises because of the immediacy of the threat - "long-term" here means "long-lasting," not "slow to mature" - the size of the economic stake, and the degree of public concern.

Priority A.2 is assigned to the general problem area of the particle content of the atmosphere and its effect on climate. This is a truly long-term problem - the potential effects would be slow to mature, but might be catastrophic if allowed to mature. The problem has many facets and can be attacked piecemeal in a sustained series of relatively

modest steps. If there is an environmental threat, it is soluble in principle by control and abatement. The long-term indirect effects of the particle load of the atmosphere on biosystems *per se* are assessed with priority B.1 because these are secondary considerations to the purpose of this report. EPA doubtless feels a more direct responsibility for research on the control of acute pathological effects, but this also is not the subject of this report.

The lower priority (B.2) assigned to work on the CO_2 content of the atmosphere as it relates to possible climatic change reflects the very long-term nature of the potential threat. It is important that this should not mean that no work on this subject is funded. Together with the suggested funding levels the priority is intended to reflect the level of effort which it is reasonable to support at this time.

A comment seems called for on the priorities assigned to research on the theory of climate. It is not at present possible to do more than speculate on the climatic sequel to any change in atmospheric composition. This is certainly a matter of concern to EPA, whose mission involves regulation of man-made changes in atmospheric composition. Indications are that the problem is one of extreme complexity. Some consider it the central problem of atmospheric science. EPA should encourage work on it, but it is the primary task of other agencies. However, it is suggested that present conditions are such that EPA could stimulate effort by giving high priority (A category) to a limited exercise to expose the "state-of-the-art."

Priorities in the problem areas are summarized in Table II, which also contains a suggestion as to the proportion of funding to be devoted to each priority area. This figure was arrived at after compilation of Table III, a list of research projects with assessed priorities. These priorities arise primarily because of the priority assigned to the problem with which they are associated, but other matters, such as cost and the likelihood of early useful return, were considered. Table IV summarizes the project priority assignment. A few projects, which bear on more than one major problem area, appear in two sets in this Table.

TABLE I. THE MAJOR PROBLEM AREAS

	Problem	Nature of potential impact	Space scale of problem	Acceptable or required time scale of effort	Major action area involved	APCO priority	Comments
I	Polluted (particularly acid) precipitation	Biological productivity	Local to contential	Immediate and short-term	Control and abatement of emissions. Energy policy	A.1	
II	Particle content of the atmosphere	Climate change	All scales	Long-term	Control and abatement of emissions.	A.2	
III	Particle and trace gas content of the stratosphere	Climate change Health	Widespread	Immediate and short-term	Air transport policy Control and abatement of emissions	A.1	"Health" refers to indirect health effect through modification of solar radiation.
IV	Particle and trace gas content of the troposphere	Biological productivity Health	Widespread	Short-term	Control and abatement of emissions	B.1	Biological effect of modification of solar radiation.
V	CO_2 content of the atmosphere	Climate change	Global	Long-term	Energy policy and population distribution	B.2	Limited initial effort B.1.
VI	CO_2 partition between atmosphere, ocean and biosphere	Biological productivity	Global	Long-term	Energy policy	C.1	
VII	Theory of climate	(Climate change)	(Global)	Long-term	Energy policy. Control and abatement of emissions Population distribution	C.1	Limited initial effort (survey) A.1 or B.1.
VIII	Heat and water emissions	Climate change Local climate	Global Very local	Long-term Short-term	Energy policy and population distribution Control and abatement	C.2 A.1	

TABLE II

Priority Summary (Problems)

Priority A.1	Suggested funding level 45% of available funds	
	Problem I	Acid precipitation
	Problem III	Particle and trace gas content of stratosphere
	Problem VII (part)	Climate theory and modeling (initial survey only)
Priority A.2	Suggested funding level 25%	
	Problem II	Particle content of the atmosphere (climatic effects)
Priority A.3	Funding from the A.2 allocation	
	Problem VIII (part)	Local heat and water emissions - persistent weather effects
Priority B	Suggested funding level 20%	
Priority B.1		
	Problem IV	Particle and trace gas content of the atmosphere and its effect on solar radiation (with reference to long-term biological and health effects).
Priority B.2		
	Problem V	CO_2 content of atmosphere (with reference to climatic effects).
Priority C	Suggested funding level 10%	
Priority C.1		
	Problem VI	CO_2 content of atmosphere, oceans, and biosphere (with reference to biological productivity).
	Problem VII	Climate theory and modeling
Priority C.2		
	Problem VIII	Heat and water emissions (climate effects)

TABLE IIIA. RESEARCH PROJECTS—ENVIRONMENTAL STUDIES
(Studies involving commonly made observations or special surveys of the state of the environment, with no conscious modification of the sources of contaminants.)
Local (<10^2 km^2) and regional (10^5 km^2) scales

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant?	Are there short-term implications of equal or higher priority?
		Air and precipitation chemistry				
1	46	Statistical and other studies of trends in the composition of the atmosphere and of precipitation (see project 46 for details of contaminants).	I, II, III, IV, V	A.2	Yes	Yes
2	46, 52	Surveys, particularly long-term surveys of precipitation chemistry. (See project 46 for details of contaminants.)	I	A.2	Yes	Yes
3		Specifically, precipitation chemistry survey of Northeastern U.S.A.	I	A.2		
4	11, 17, 20, 34, 46, 49, 53	Collection and physical and chemical examination of airborne particles.	II, III, IV	A.1	Yes	Yes
5	19, 26, 27, 29, 30, 32, 33, 43, 46	Regional mass balance of S(H_2 SO_4) and N (HNO_3) including catalytic oxidation of SO_2 and washout studies.	I, II, III	A.1	Yes	Yes
		Fog, cloud and precipitation				
6		Influence of cities on cloud and precipitation distribution, e.g., by study of gauge-calibrated records.	II, VIII	C.1	Yes	
7	9	Influence of water and heat emissions (e.g., cooling towers) on micro- and meso-climate.	III, VI	A.3	Yes	Yes, higher
		Visibility				
8	18, 54	Statistical and other studies of trends.	II	B.3	Yes	
9	8	Effects of emission of hygroscopic material	II	A.3	Yes	Yes

TABLE IIIA (Cont.)

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant?	Are there short-term implications of equal or higher priority?
		Solar and terrestrial radiation				
10	34, 45, 46	Comparison of solar radiation recorded at urban and rural stations (direct and scattered radiation, total energy and spectral distribution).	II, IV	B.1	Yes	
11	22, 34, 37, 38, 45, 46	Investigation of the nature and concentration of atmospheric particles by relation of solar radiation observations to transmission models	II	A.2	Yes	Yes
12	22, 34, 37, 38	Aircraft and balloon surveys of flux divergence of solar and terrestrial radiation.	II	A.3 B.1	Yes	
13	34, 37, 38 39, 45	Surveys of the extinction of u-v radiation.	IV	B.1	Yes	
		Temperature				
14		Surveys of urban "heat islands."	II, VIII	C.2	Yes	Yes, higher
15	37	Simultaneous airborne and tower studies of vertical temperature structure and pollutant concentration.	II, VIII	C.2	Yes	Yes, higher

TABLE IIIB. ENVIRONMENTAL STUDIES ON CONTINENTAL AND GLOBAL SCALES

Project area #	Directly related project areas	Project description	Related major problems	Priority
16	54	<u>Cloud, precipitation and visibility</u> Study of trends and spatial distribution relative to sources of emissions. Specifically, study of trends and distribution of cirrus cloud relative to aircraft emissions.	II, VIII	A.3 (A.2 cirrus)
17	53	Survey of global distribution of condensation and ice nuclei (prior to monitoring).	II	A.2
18	49	<u>Mass balance of particles and trace materials</u> Global survey and identification studies of stratospheric particles, (aircraft surveys, prior to monitoring).	III	A.1 B.1
19	5, 30, 32, 33, 46, 55	Studies of the global distribution and cycling of major pollutant elements (particularly S and N) with particular attention to the fate of emissions from the major pollutant sources. (e.g., What happens to S emitted in the N.E. coastal strip? What happens to N emitted in the Los Angeles basin?)	I, II	A.1
20		Surveys of the magnitude of natural and (separately) agricultural sources of airborne particles.	II, III, IV	A.1
21	35, 44	<u>Mass balance of CO_2</u> Study of partition and cycling of CO_2 between solid earth, oceans, biosphere and atmosphere.	V, VI	B.2
22	11., 12, 45	<u>Global energy balance</u> Study of upward and downward solar and terrestrial radiation fluxes at the ground and from balloons, aircraft and satellites, particularly in relation to those expected in a "clean" atmosphere.	II	A.2
23	54	Studies related to the global albedo; specifically to the feasibility of long-term monitoring, (e.g., satellite radiation and cloud surveys and the variability of radiation balance on various space scales).	II, V, VIII	A.2

TABLE IIIC. FIELD EXPERIMENTS ON LOCAL AND REGIONAL SCALES
(Field experiments are studies involving purposeful modification of the environment or of emissions into the environment and experiments in monitoring)

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant?	Are there short-term implications of equal or higher priority?
		Tracer studies				
24		"Meteorological" tracer studies of urban modification of wind field. (e.g., F.P. tracer)	VIII	C.2	Yes	Yes, higher
25	19, 26, 27	"Plume" tracer studies of the travel (and by inference, the transformation) of contaminants (e.g., using SF_6 or similar tracer with simultaneous mapping of normal pollutant).	I, II	A.3	Yes	Yes, higher
		"Fuel switch" experiments (source modification)				
26	19, 25, 27	Interrelationship of SO_2, SO_3 and particle content.	I, II, VIII III, IV	A. 3	Yes	Yes, higher
27	19, 25, 26	Interrelationship of oxidant and reducing pollutants.	I, II	A.3	Yes	Yes, higher
		Experimental monitoring				
28		Development of laser sounding for tropospheric particles.	II, IV	B.1	Yes	Yes, higher
29		Detection of chemically significant trace and transient intermediate constituents of polluted atmospheres by spectroscopic and other means.	I, II, III	B.2	Yes	Yes, higher

TABLE IIID. FIELD EXPERIMENTS ON CONTINENTAL AND GLOBAL SCALES

Project area #	Directly related project areas	Project description	Related major problems	Priority
30	5, 19, 43	Tracer studies Long-distance tracer study of SO_2/SO_3 transport and wash-out.	I	A.1
31	50	Experimental monitoring Study of quantitative use of lasers for monitoring stratospheric aerosol with long-term stability.	VII	A.1

TABLE IIIE. LABORATORY EXPERIMENTS

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant?	Are there short-term implications of equal or higher priority?
		Air chemistry				
32	5, 20	"Large scale laboratory" investigation of the chemistry of SO_2 oxidation—catalysis by suspended particles; influence of humidity, NO_x and other trace gases.	I, II	A.1	Yes	Yes
33	5, 20	Modification of NO_x-O_3-hydrocarbon photochemistry in the presence of SO_2 and particles.	I, II	A.2	Yes	Yes, higher
34	10, 11, 12, 13, 37, 38, 39	Laboratory determination of the optical properties of bulk samples of substances, and mixtures identified in collections of atmospheric particles.	II	A.2	Yes	Yes
		Experimental monitoring				
35	21, 44	Development of an absolute CO_2 monitor (e.g., mass spectrograph).	V, VI	C.1		
36		Laboratory investigations and field trials relative to the development of new techniques for sensing contaminants, particularly "secondary" contaminants, by physical and chemical methods.	I, II	A.3	Yes	Yes, higher

TABLE III F. THEORETICAL AND NUMERICAL STUDIES

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant?	Are there short-term implications of equal or higher priority?
		Radiative transfer Effect of specified (particularly observed) particle content on scattering and absorption of solar and terrestrial radiation.				
37	11, 12, 13, 15, 34, 40	(a) urban boundary layers	II, IV	A.3	Yes	Yes, higher
38	11, 12, 13, 34, 39	(b) relatively uncontaminated atmospheres (including stratosphere).	II, III, IV	A.2		
		Radiative transfer/photochemistry				
39	13, 19, 34, 38, 49	Quantitative photochemistry of the lower stratosphere on various assumptions concerning pollution, with attention to the transmitted u.v. radiation.	III	A.1		
		Numerical models of the meteorological effects of pollution				
40	37	Boundary layer models in polluted atmospheres (with radiation).	II	A.3	Yes	Yes, higher
41		Climatic effects of extended sources of pollutant (including heat and water) emissions, using current meteorological models, (the Megalopolis problem).	II, V, VIII	A.2		
42		Global climatic models.	VII	C.1 (limited effort A.1)		
		Numerical models of pollution transport				
43	30	Regional/continental scale models of transport and deposition of SO_2/SO_3.	I	A.1	Yes	Yes

TABLE III G. MONITORING

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant?	Are there short-term implications of equal or higher priority?
		"Long-term aspects of current monitoring activities"				
		Establishment or designation of urban, rural and remote "benchmark" stations concerned with long-term stability or standards for -	I, III, IV			
44	21, 35	CO_2 monitoring	V, VI			
45	10, 11, 13, 22, 52	Detailed monitoring of solar radiation	II, III, IV	A.2		
46	1, 2, 4, 5, 19	Air and precipitation chemistry, monitoring -	I, II, III, IV	A.1		Yes
	10, 11	Acidity Materials relevant to the sulphur and nitrogen cycles. Metals—potential poisons Pb, Hg, Cd, Be, etc. potential catalysts Cr, Mn, Va, etc. Persistent gaseous or readily vaporized or dispersed materials in industrial use—Asbestos, polychlorinated biphenyls, fluorinated compounds such as SF_6, etc. Turbidity	II	A.2		
		Monitoring of areal averages of pollutant concentration				
47		Development of statistical techniques	I, II	A.3	Yes	Yes, higher
48	29, 31, 36	Remote sensing techniques	I, II	A.3	Yes	Yes, higher

TABLE III G (Cont.)

Project area #	Directly related project areas	Project description	Related major problems	Priority	Is the proposed regional study relevant	Are there short-term implications of equal or higher priority?
		<u>Stratospheric monitoring</u>				
49	18	Particle and trace gas content by direct sampling and integrating optical methods.	III	A.1		
50	31	Laser monitoring	III	A.1		
51	45	Monitoring of spectral distribution of solar u.v. radiation reaching the surface in remote areas.				
		<u>Remote area (particularly oceanic) surveys</u>				
52		Chemistry of precipitation in remote ocean areas	I	A.3		
53	4, 8, 17	Particle, condensation nucleus and ice nucleus content in remote ocean areas.	II	A.3		
		<u>Monitoring from space</u>				
54	23	Global albedo	I, V, VII, VIII	B.1 (feasibility studies A.2)		
55	19, 29	Trace constituents of the atmosphere	I, II	A.3		Yes, (higher?)

TABLE IV

Priority Summary (Projects)

Priority A1 - 15 Projects

4	20	39	49
5	30	(42)	50
18	31	43	51
19	32	46	

Priority A2 - 15 Projects

1	16	33	45
2	17	34	46
3	22	38	(54)
11	23	41	

Priority A3 - 15 Projects

7	25	37	52
9	26	40	53
12	27	47	55
16	36	48	

Priority B1 - 6 Projects

10	18
12	28
13	54

Priority B2 - 3 Projects

21	29	44

Priority B3 - 1 Project

8

Priority C1 - 3 Projects

6	35	42

Priority C2 - 3 Projects

14	15	24

( ) indicates limited effort on a project of generally lower priority.

4. DESCRIPTION OF SELECTED HIGH-PRIORITY RESEARCH AREAS

4.1 PROJECTS CONNECTED WITH THE 'ACID PRECIPITATION' PROBLEM

This problem exists on all space scales. It is perhaps most serious on the large regional to continental scales because on this scale it has international repercussions and cannot be minimized by land use planning in the 'receptor' areas as it might be on smaller scales.

Projects 5 and 19 - Mass Balance of Pollutant Sulfur and Nitrogen

The broad objective is to determine how, where, and in what chemical form pollutant SO_2 and nitrogen oxides are removed from the atmosphere. (This statement does not imply that no fraction of these pollutants is retained in the atmosphere, for example, in a very slow build-up of stratospheric pollution, but does imply that any retained amounts would be small and not likely to be detected by mass-balance methods. A wide variety of approaches seems to exist on scales from very local to global.

(a) Plume Studies - The degree to which SO_2 and NO are converted to H_2SO_4, HNO_3 and their salts in the plumes from major sources, mainly fossil-fuel burning electricity generating stations. This involves sampling of stack gases and sampling within the plume so far as it can conveniently be identified. The type of problem to be considered is the existence and magnitude of catalytic oxidation of SO_2 (e.g., with an oil burning plant do vanadium oxide or other rarer metal oxides catalyse this oxidation in the plume) or possible photochemical reactions of NO (e.g., would an isolated source with appreciable NO and low SO_2 content lead to high

concentrations of NO_2 and HNO_3). This type of research is essential to an understanding of the long-term problem of polluted rainfall but it also has relevance to acute short-term problems and is perhaps best pursued in this context.

(b) Regional Source Studies - Relation of the total emission of pollutant within a city to that exported through a ring of say 50 km radius, and that deposited within the ring, using surface and airborne sampling (including long-path spectrographic sampling). Such studies have relevance to acute short-term problems and will presumably be a major feature of the proposed EPA regional study.

(c) Regional Sink Studies - By airborne and surface sampling, determine the amount of a pollutant gas entering a relatively unpolluted area and remaining there, (e.g., there are measurements that suggest that for certain wind directions the State of Connecticut is, on balance, a sink region for gaseous SO_2 in spite of considerable internal emissions. There are no measurements to show what happens to this SO_2, and in what chemical transformation it is deposited or exported.) This type of study could, with advantage, be combined with the regional precipitation survey.

Project 30 - Tracer Studies of Long-distance Transport of Wash-out of SO_2/ SO_3

The object of this investigation would be to identify the source area of the pollutants in acid precipitation. The distance involved would be of order hundreds of km. The planning of field experiments would be based on preliminary

study of mass balance and of trajectories, and their execution on forecast trajectories. There are difficulties in choice of tracer since the wash-out process is an essential part of the mechanism to be investigated. SF_6 and similar substances might be used to check trajectories at these distances, but the behavior of these tracers in cloud and precipitation would itself be a subject for research. The possibility of identifying pollution sources from the isotopic composition of sulfur in rainfall and fuels should be investigated.

This work would call for deployment of very considerable resources, comparable with those contemplated for the regional study, though on a larger space scale. There is a case for considering it as an extension of the regional study.

Project 3 - Precipitation Chemistry Survey of Northeastern U.S.A. (associated project 5, 19, 30)

The object of this research would be to determine the composition of precipitation over the area and to identify the source of any contamination. Parallel work on the biological consequences should be encouraged. A possible approach would be -

(a) Survey existing projects for determination of the amount and nature of dry fall-out and chemical analysis or rainfall and snowfall within the area.

(b) Arrange for maintenance of a permanent record of simple measurements (especially of p_H) at a considerable number of stations, and for careful and very thorough analysis

at a few (about five) stations. This analysis should include searches for trace amounts of toxic materials as well as the more common ions. Sampling arrangements at these stations should allow examination of the precipitation in selected storms and some relation of dry fall-out to wind systems.

(c) By estimation of the total mass of contaminant and examination of meteorological charts (or ultimately preparation of a large-scale transport and diffusion model) an attempt should be made to identify the source of the contamination or dry fall-out.

4.2 PROJECTS CONNECTED WITH THE PARTICLE CONTENT OF THE LOWER STRATOSPHERE

The problem has aspects which call for study on different time scales. The first concerns the potential modification of the lower stratosphere by the emissions of supersonic transport aircraft, if traffic there is developed to the extent which will be necessary to render the introduction of such aircraft commercially viable. The second concerns the possibility of a much slower build-up of pollution in the lower stratosphere not connected with airborne sources.

Project 18 - Global Survey and Identification Studies of Stratosphere Particles

It is important to determine the origin of the sulphate particles of the stratosphere layer as it exists now. Is it primarily of volcanic origin? Does sulphate and ammonia of biological origin predominate? Is industrially

produced sulphate of importance? There is no very obvious line of attack. Samples must be taken in situ for examination of individual particles and of composition in bulk, and continuous monitoring of total quantity by direct or remote sensing must begin. Amounts must be correlated with volcanic activity and aircraft operations -- at present, of military and prototype transport aircraft. The possibility of source identification through the sulfur isotope ratio of the particles, and of the various possible sources, should be investigated in field trials.

Projects 28, 31 and 51 - Laser Sounding of the Stratosphere

In view of the short-term urgency of the 'SST' aspect of the problem, it seems advisable to establish routine monitoring of the lower stratosphere by observing backward scattering from a laser beam (lidar) using well-established techniques and expert subjective assessment of the results. The current major shortcoming of lidar monitoring is the absence of any absolute reference standard and the difficulty of good relative comparison from day to day, mainly because of very variable particle content of the troposphere. There is no level in the atmosphere which can be assumed free of particles to provide a reference signal which can be related to molecular scattering. Various devices have been suggested to circumvent this difficulty; they all employ multiple beams of different wavelengths, or a "tunable" laser, and rely either on the different wavelength dependence of scattering by molecules and particles or on inelastic (e.g., Raman) scattering by molecules of a permanent atmospheric gas.

Until a more absolute method is established, the best prospect of

remote monitoring of stratospheric particle content appears to be establishment of current state-of-the-art lidar sounding at a few localities, preferably at high altitude, where clean, cloud-free tropospheric air is frequent.

Project 39 - Quantitative Photochemistry of the Lower Stratosphere

This investigation would be a theoretical study of the repercussions of a change in the water content of the lower stratosphere and possibly of the introduction of other trace gases. A wide but not completely unrealistic range of rates of introduction should be studied. A major objective would be to determine the overall effect on the transmission of ultra-violet radiation in the wavelength region of the present ozone cut-off. If an increased intensity of ultra-violet radiation of this wavelength were to reach the earth's surface, biological and health effects would require close study.

4.3 PROJECTS CONNECTED WITH VERY-LONG-TERM CLIMATIC CHANGE

Project 21 - The Partition and Cycling of CO_2

The object of this research would be quantitative understanding of the partition of added CO_2 from fossil fuel combustion between the atmosphere, the biosphere, the oceans and ultimately the solid earth. The problem is complex and subject to attack on many facets. There seems to be most uncertainty at present concerning the reactions with the biota, both terrestrial and oceanic; an uncertainty which might affect not only estimates of the final mass balance but also the reliability of certain methods of

investigating the ocean-atmosphere interchange. It seems that a critical study of current knowledge, with particular reference to the role of biota, would be most useful in guiding the planning of further research.

Projects 22 and 12 - The Global Energy Balance

These projects are concerned with measurements in the field of solar and terrestrial radiation. The major uncertainties are related to the optical properties of cloud and aerosol. Whilst much progress in the study of the optics of aerosol can be expected from laboratory investigation (Project 34), the optical properties of cloud must be investigated in the field as well as by numerical investigation of "clean" cloud models, (i.e., assemblies of droplets of pure water). EPA's specific interest is in determining the effects of man-made pollutant on the climate, and it is necessary to determine firstly whether the difference between the bulk radiative properties of "clean atmosphere" models and those of the real atmosphere, as measured in the field, are caused by man-made pollutant, and secondly, whether the resultant changes in energy balance are climatically significant.

The global albedo is the most obvious single-parameter indicator of climate -- it correlates directly with the mean temperature of the planet. It is important to determine whether, and on what time-scale of averaging, the global albedo can be determined by observation from space; what variability is to be expected on this and longer time scales, and what precision and long-term stability of observation is required to detect significant trends. A paper study is called for in the first instance.

Project 42 - Global Climatic Models

This is a problem whose resolution, if attainable, will require enormous resources. It is at present attracting the attention and stimulating the imagination of many competent meteorologists and mathematicians, but it is a formidable problem for any institution to attack in isolation, EPA should not and could not take the lead, financial or scientific, but it might provide a critical stimulus. It would be valuable to seek a concensus of opinion on favored methods of attack, scales of effort considered useful, and the availability of manpower and machine power.

5. Outline Rate of Expenditure and Timing of Projects

Many of the projects listed in Table III would depend for their successful prosecution on the initiative and imagination of small teams with modest resources. It is not productive to schedule work of this type, nor to apply priorities, too rigidly. An imaginative proposal in an A2 or A3 priority area might take precedence over a pedestrian effort in an A1 area. Some projects do, however, call for deployment of major resources, and have minimum useful levels of expenditure, set by the cost of the equipment needed. For example, addition of stratospheric monitoring by laser to an existing establishment calls for a first-year expenditure of order $200K.

Chart I suggests in outline the broad divisions of an expenditure of $1,000K per year for five years. Instrumentation costs do not allow a balanced program at much lower expenditure. Even this level assumes much cost-sharing with other EPA projects (such as the Regional Study), and with other agencies interested in the area of monitoring and measurement. For example, it is assumed that the program will not be charged pro-rata with the operating costs of aircraft engaged in stratospheric sampling. In the monitoring and measuring area, which in Chart I accounts for half the expenditure, it is further assumed that the program will support research and development in methods and requirements, including the operation of prototype equipment, but not permanent monitoring installations.

CHART I

RATE OF EXPENDITURE

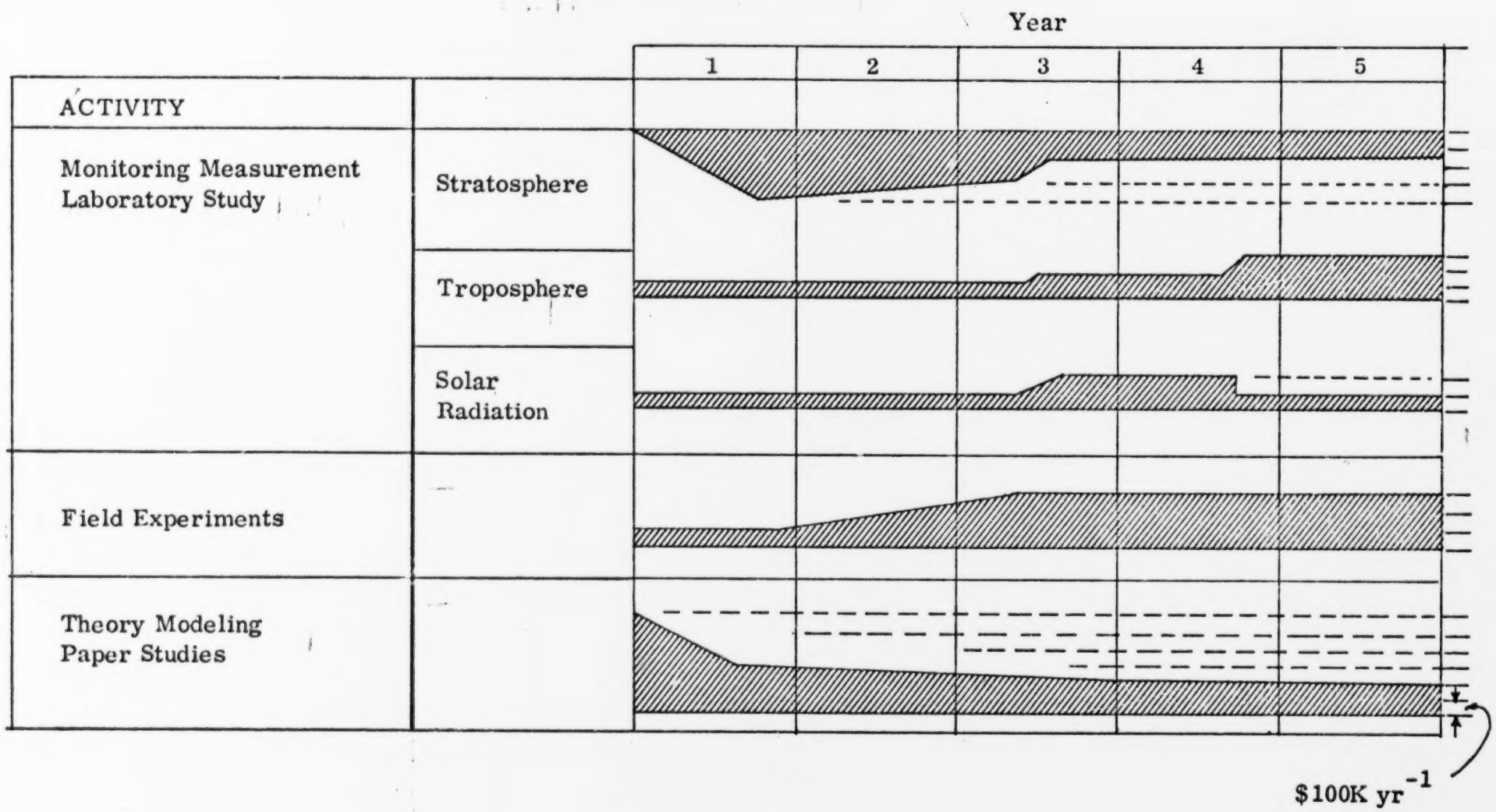

CHART II

TIMING OF SOME MAJOR PROJECTS

	Year 1	2	3	4	5
Develop and Test Stratosphere Laser Probe					
Support Troposphere Remote Sensing Development					
Support Global Albedo Hardware					
Install or Re-equip Solar Radiation Stations					
Long-Range Tracer Field Experiment					
Feasibility Studies Global Albedo Climate Models Long-Range Tracer Experiment					

Chart II lays out a suggested timing of the most expensive projects which account for the major variations of rate of expenditure in Chart I. The two charts imply an overall proportion of about 65-35 between equipment costs and manpower, computer, and other costs.